#9

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 899 107 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
03.03.1999 Bulletin 1999/09

(51) Int. Cl.[6]: **B41J 2/14**

(21) Application number: **98116469.2**

(22) Date of filing: **01.09.1998**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **01.09.1997 JP 251307/97**
14.10.1997 JP 280677/97
17.08.1998 JP 230517/98

(71) Applicant:
SEIKO EPSON CORPORATION
Shinjuku-ku Tokyo (JP)

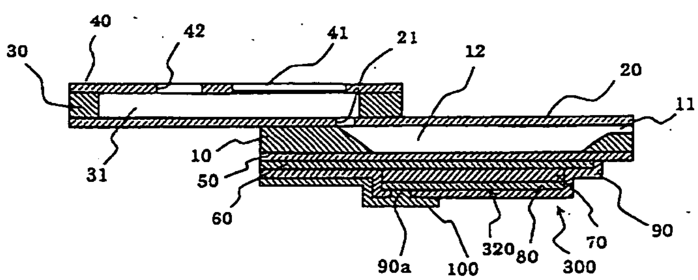
(72) Inventors:
- **Takahashi, Tetsushi**
Suwa-shi, Nagano-ken (JP)
- **Miyata, Yoshinao**
Suwa-shi, Nagano-ken (JP)
- **Yazaki, Shiro**
Suwa-shi, Nagano-ken (JP)

(74) Representative:
Diehl, Hermann, Dr. Dipl.-Phys. et al
DIEHL, GLÄSER, HILTL & PARTNER
Patentanwälte
Flüggenstrasse 13
80639 München (DE)

(54) **Ink-jet printer**

(57) An ink-jet printing head and an ink-jet printing apparatus using same comprising a piezoelectric element (300) constituted substantially, via a vibrating plate constituting a part of a pressure generating chamber (12) communicating with a nozzle aperture (11), by a lower electrode (60), a piezoelectric layer (70), and an upper electrode (80), wherein said vibrating plate in an area opposite to the vicinity of at least one end in the longitudinal direction of a piezoelectric active part (320) which is an area in which said piezoelectric layer (70) substantially drives said vibrating plate is convex on the reverse side to said piezoelectric element (300).

FIG.2B



EP 0 899 107 A2

Description

[0001] The present invention relates to an ink-jet printer, specifically to an ink-jet printing head and an ink-jet printing apparatus.

[0002] For an ink-jet printing head for ejecting ink droplets from nozzle apertures wherein a vibrating plate constitutes a part of a pressur generating chamber communicating with a nozzle aperture for ejecting an ink droplet and ink in the pressure generating chamber is pressurized by deforming the vibrating plate by a piezoelectric element, there has been practically known a couple of types including one type that a piezoelectric actuator in a longitudinal vibration mode which expands or contracts in the axial direction of a piezoelectric element is employed and the other type that employs a piezoelectric actuator in a flexural vibration mode. For the former type, the volume of a pressure generating chamber can be varied by touching the end face of a piezoelectric element to a vibrating plate and a head suitable for high density printing can be manufactured, while this type would suffer from a problem that a difficult process for cutting a piezoelectric element like the teeth of a comb with the piezoelectric element fitted to pitch between nozzle apertures and work for positioning and fixing the cut-out piezoelectric vibrator on a pressure generating chamber are required and, further, the manufacturing process is complicated.

[0003] On the other hand, for the latter, a green sheet formed of a piezoelectric material is stuck in the shape of a pressure generating chamber and a piezoelectric element can be fixed on a vibrating plate in a relatively simple process that the green sheet is burnt. However, since the flexural vibration is utilized, there would arise a problem that area to some extent is required and high density arrangement is difficult to achieve.

[0004] To solve the problem of the latter printing head, a method of forming a uniform piezoelectric material layer on the whole surface of a vibrating plate by film forming technique and forming a piezoelectric element by cutting the piezoelectric material layer in a shape corresponding to a pressure generating chamber by lithography so that the cut piezoelectric material layer is independent for every pressure generating chamber is proposed as disclosed in Unexamined Japanese Patent Publication No. Hei. 5-286131.

[0005] Hereby, there is an advantage in that no work-step is required for sticking a piezoelectric element on a vibrating plate, not only a piezoelectric element can be fixed by a precise and simple method called lithography but the piezoelectric layer can be formed so that it is thin and can be driven at high speed.

[0006] In this case, a piezoelectric element corresponding to each pressure generating chamber can be driven by providing at least only an upper electrode for every pressure generating chamber with the piezoelectric material layer provided on the whole surface of the vibrating plate. However, it is desirable in view of the quantity of displacement per unit driving voltage and stress applied to the piezoelectric layer in a part opposite to each pressure generating chamber and a part crossing the outside that a piezoelectric active part composed of the piezoelectric layer and each upper electrode is provided in an area opposite to each pressure generating chamber or at least a part except one end is formed within the area opposite to each pressure generating chamber.

[0007] However, when the piezoelectric active part in which an upper electrode pattern is formed on the piezoelectric layer is driven, a crack is readily made particularly at the end of the piezoelectric active part and the piezoelectric active part may be fatally damaged.

[0008] If the end of the piezoelectric layer is designed to extend up to the peripheral wall of a pressure generating chamber, there is a problem that a crack is generated in a part opposite to the vicinity of a boundary between the pressure generating chamber and the peripheral wall.

[0009] These problems readily occur particularly in a case where the piezoelectric material layer is formed by film forming technique. The reason for this is that as the piezoelectric material layer formed by the film forming technique is very thin, the rigidity is lower, compared with that in case a piezoelectric element is stuck.

[0010] It is, therefore, the object of the present invention to overcome the drawbacks of the prior art products, as e.g. for a conventional ink-jet printing head. This object is solved by an ink-jet printing head and an ink-jet printing apparatus according to the independent claims 1 and 13. Further advantageous features, aspects and details of the invention are evident from the dependent claims, the description and the drawings. The claims are to be understood as a first non-limiting approach to define the invention in general terms.

[0011] This invention relates to an ink-jet printing head and an ink-jet printing apparatus using same in which a vibrating plate constitutes a part of a pressure generating chamber communicating with a nozzle aperture for ejecting ink droplets, a piezoelectric element is provided via the vibrating plate and ink droplets are ejected by displacement of the piezoelectric element.

[0012] One aspect of the present invention is to provide an ink-jet printing head and an ink-jet printing apparatus using same capable of preventing a crack from occurring due to stress concentration and fatigue failure at the end of a piezoelectric active part and in the vicinity of a boundary between a pressure generating chamber and the peripheral wall.

[0013] An ink-jet printing head according to a first aspect of the present invention for solving the above problems is based upon an ink-jet printing head which includes a pressure generating chamber communicating with a nozzle aperture, a vibrating plate constituting a part of the pressure generating chamber and a piezoelectric element corresponding

to the pressure generating chamber, and the piezoelectric element comprising a lower electrode, a piezoelectric layer, and an upper electrode, and the vibrating plate in an area opposite to the vicinity of at least one end in the longitudinal direction of a piezoelectric active part of the piezoelectric element is convex to the pressure generating chamber.

[0014] According to such a first aspect, no tensil stress from the vibrating plate is applied to the end of the piezoelectric active part when the piezoelectric layer driving the vibrating plate is driven and stress concentration is reduced.

[0015] An ink-jet printing head according to a second aspect of the present invention is based upon the ink-jet printing head according to the first aspect and has a difference in that the vibrating plate in an area opposite to the vicinity of the end of the above piezoelectric active part is convex to the pressure generating chamber when the piezoelectric element is driven and is convex to the piezoelectric element when the piezoelectric element is not driven.

[0016] According to such a second aspect, stress concentration on the piezoelectric active part at least when the piezoelectric element is driven is avoided.

[0017] An ink-jet printing head according to a third aspect of the present invention is based upon the ink-jet printing head according to the second aspect and has a difference in that stress in a direction in which the above vibrating plate is compressed is applied to the vicinity of the surface on the side of the piezoelectric layer of the vibrating plate in an area opposite to the vicinity of the end of the piezoelectric active part when the piezoelectric element is driven.

[0018] According to such a third aspect, the vibrating plate opposite to the vicinity of the end of the piezoelectric active part is compressed and no tensile stress is applied to the end of the piezoelectric active part when the piezoelectric element is driven.

[0019] An ink-jet printing head according to a fourth aspect of the present invention is based upon the ink-jet printing head according to any of the first to third aspects with a difference in that clearance between the end of the piezoelectric active part and the peripheral wall of the pressure generating chamber outside the piezoelectric active part is set to a range 0.3 to 5 times as wide as the width of the pressure generating chamber.

[0020] According to such a fourth aspect, no tensile stress is applied to the end of the piezoelectric active part when the piezoelectric element is driven by arranging the end apart from the peripheral wall by predetermined distance.

[0021] An ink-jet printing head according to a fifth aspect of the present invention is based upon the ink-jet printing head according to any of the first to the fourth aspects with an additional feature in that the end of the piezoelectric active part is the end of the piezoelectric layer provided to an area opposite to the pressure generating chamber and the lower electrode and the upper electrode effectively exist at the end of the piezoelectric layer.

[0022] According to such a fifth aspect, the end of the piezoelectric layer patterned in the area opposite to the pressure generating chamber is prevented from being broken and peeled.

[0023] An ink-jet printing head according to a sixth aspect of the present invention is based upon the ink-jet printing head according to the fifth aspect with a feature in that the end of the piezoelectric active part is the ends of the piezoelectric layer and the upper electrode patterned in an area opposite to the pressure generating chamber.

[0024] According to such a sixth aspect, the ends of the piezoelectric layer and the upper electrode are prevented from being broken and peeled off.

[0025] An ink-jet printing head according to a seventh aspect of the present invention is based upon the ink-jet printing head according to any of the first to fourth aspects and is characterized in that a piezoelectric inactive part in which a piezoelectric layer not substantially driven exists is continuously provided outside at least one end in the longitudinal direction of the piezoelectric active part.

[0026] According to such a seventh aspect, the vicinity of an area opposite to a boundary between the pressure generating chamber and the peripheral wall is prevented from being broken and the lower electrode can be led to the pressure generating chamber via the piezoelectric inactive part.

[0027] An ink-jet printing head according to an eighth aspect of the present invention is based upon the ink-jet printing head according to any of the first to fourth aspects with a feature in that a piezoelectric inactive part, in which at least the width of the piezoelectric layer is narrower than the width of the piezoelectric active part and which does not substantially drive the vibrating plate, exists and is continuously provided outside at least one end in the longitudinal direction of the piezoelectric active part although the piezoelectric inactive part is provided with the piezoelectric layer, the above lower electrode and the above upper electrode.

[0028] According to such an eighth aspect, the vicinity of an area opposite to a boundary between the pressure generating chamber and the peripheral wall is prevented from being broken and voltage can be applied via the piezoelectric inactive part.

[0029] An ink-jet printing head according to a ninth aspect of the present invention is based upon the ink-jet printing head according to the seventh or eighth aspect and is further characterized in that the piezoelectric inactive part is provided in at least one direction of the piezoelectric active part in the longitudinal direction and is extended up to the peripheral wall of the pressure generating chamber.

[0030] According to such a ninth aspect, application to the piezoelectric active part is executed via the piezoelectric inactive part pulled outside the pressure generating chamber.

[0031] An ink-jet printing head according to a tenth aspect of the present invention is based upon the ink-jet printing

head according to any of the first to ninth aspects with a difference that an insulating layer is formed on the upper surface of the piezoelectric active part and a contact part which is a connection of the upper electrode and a lead electrode is formed in a contact hole formed in the insulating layer.

[0032] According to such a tenth aspect, voltage is applied to the piezoelectric active part via the contact part in the contact hole formed in the insulating layer.

[0033] An ink-jet printing head according to an eleventh aspect of the present invention is based upon the ink-jet printing head according to the tenth aspect with an additional feature that a contact part which is a connection of the upper electrode and a lead electrode is formed in an area which continues as far as the piezoelectric inactive part on the peripheral wall of the pressure generating chamber.

[0034] According to such an eleventh aspect application to the piezoelectric active part is executed via the contact part provided outside the pressure generating chamber.

[0035] An ink-jet printing head according to a twelfth aspect of the present invention is based upon the ink-jet printing head according to any of the first to eleventh aspects and is further characterized in that the pressure generating chamber is formed in a monocrystalline silicon substrate by anisotropic etching and the vibrating plate and the piezoelectric element are formed by film forming technique and lithography.

[0036] According to such a twelfth aspect, the ink-jet printing head provided with high density nozzle apertures can be relatively readily manufactured in large quantities.

[0037] An ink-jet printing apparatus according to a thirteenth aspect of the present invention is characterized in that it is provided with the ink-jet printing head according to any of the first to twelfth aspects.

[0038] According to such a thirteenth aspect, the ink-jet printing apparatus in which the reliability of the head is enhanced can be realized.

Fig. 1 is an exploded perspective view showing an ink-jet printing head according to an embodiment of the present invention;

Figs. 2A and 2B show an ink-jet printing head according to a first embodiment of the present invention and are a plan and a sectional view of Fig. 1;

Figs. 3A and 3B are plans showing examples in which a sealing plate shown in Fig. 1 is transformed;

Figs. 4A to 4D are sectional views showing a thin film manufacturing process in the first embodiment of the present invention;

Figs. 5A to 5C are sectional views showing the thin film manufacturing process in the first embodiment of the present invention;

Figs. 6A to 6C are sectional views showing the thin film manufacturing process in the first embodiment of the present invention;

Figs. 7A and 7B are a plan and a sectional view showing the main part of the ink-jet printing head according to the first embodiment of the present invention;

Fig. 8 is a plan showing the main part of an example in which the ink-jet printing head according to the first embodiment of the present invention is transformed;

Fig. 9 is a plan showing the main part of an example in which the ink-jet printing head according to the first embodiment of the present invention is transformed;

Fig. 10 is a plan showing the main part of an example in which the ink-jet printing head according to the first embodiment of the present invention is transformed;

Fig. 11 is a plan showing the main part of an example in which the ink-jet printing head according to the first embodiment of the present invention is transformed;

Fig. 12 is a plan showing the main part of an example in which the ink-jet printing head according to the first embodiment of the present invention is transformed;

Fig. 13 is a plan showing the main part of an ink-jet printing head according to a second embodiment of the present invention;

Fig. 14 is an exploded perspective view showing an ink-jet printing head according to the other embodiment of the present invention;

Fig. 15 is a sectional view showing the ink-jet printing head according to the other embodiment of the present invention; and

Fig. 16 is a schematic drawing showing an ink-jet printing apparatus according to an embodiment of the present invention.

[0039] In the following the present invention is described in detail with reference to the accompanying drawings.

[0040] Figs. 1 through 12 are views according to the first embodiment of the present invention. Fig. 1 is an exploded perspective view showing an ink-jet printing head according to a first embodiment of the present invention and Figs. 2 is a plan and shows the sectional structure in the longitudinal direction of one pressure generating chamber shown in

Fig. 1.

[0041] As shown in the above drawings, a passage forming substrate 10 is made of a monocrystalline silicon substrat with the orientation of a crystal face of (110) in this embodiment. Preferably, the passage forming substrate 10 is approximately 150 to 300 μm thick. More preferably, the passage forming substrate is approximately 180 to 280 μm thick and most preferably, it is approximately 220 μm thick. The reason for this is that density in arrangement can be enhanced, keeping th rigidity of a partition wall between adjacent pr ssur generating chambers.

[0042] One face of the passage forming substrate 10 is open and an elastic film 50 with the thickness of 1 to 2 μm made of silicon dioxide formed by thermal oxidation beforehand is formed on the other surface.

[0043] In the meantime, a nozzle aperture 11 and a pressure generating chamber 12 are formed on the open face of the passage forming substrate 10 by anisotropically etching the monocrystalline silicon substrate.

[0044] The above anisotropical etching is executed utilizing a character that when the monocrystalline silicon substrate is dipped in alkaline solution such as KOH, the monocrystalline silicon substrate is gradually eroded, a first crystal face (111) perpendicular to a crystal face (110) and a second crystal face (111) at an angle of approximately 70° with the first crystal face (111) and at an angle of approximately 35° with the above crystal face (110) appear and the etching rate of the crystal face (111) is approximately 1/180, compared with the etching rate of the crystal face (110). Precise working based upon the working in depth of a parallelogram formed by two first crystal faces (111) and diagonal two second crystal faces (111) can be executed by the above anisotropic etching and the pressure generating chambers 12 can be arranged in high density.

[0045] In this embodiment, the longer side of each pressure generating chamber 12 is formed by the first crystal face (111) and the shorter side is formed by the second crystal face (111). The pressure generating chamber 12 is formed by etching the passage forming substrate 10 up to the elastic film 50. The elastic film 50 is dipped by extremely small quantity in alkaline solution for etching the monocrystalline silicon substrate.

[0046] In the meantime, each nozzle aperture 11 communicating with one end of each pressure generating chamber 12 is formed so that each nozzle aperture is narrower and shallower than each pressure generating chamber 12. That is, the nozzle aperture 11 is formed by etching (half-etching) the monocrystalline silicon substrate up to the middle in the direction of the thickness. The above half-etching is executed by adjusting etching time.

[0047] The size of the pressure generating chamber 12 which applies ink droplet ejecting pressure to ink and the size of the nozzle aperture 11 for ejecting an ink droplet are optimized according to the quantity of ejecting ink droplets, ejecting speed and a ejecting frequency. For example, if 360 ink droplets per inch are to be recorded, the nozzle aperture 11 is required to be formed precisely so that the width is several tens μm.

[0048] Each pressure generating chamber 12 and a common ink chamber 31 described later communicate via an ink supply port 21 formed in the position corresponding to one end of each pressure generating chamber 12 of a sealing plate 20 described later, ink is supplied from the common ink chamber 31 via the ink supply communicating port 21 and distributed to each pressure generating chamber 12.

[0049] The sealing plate 20 is made of glass ceramics in which the above ink supply communicating port 21 corresponding to each pressure generating chamber 12 is made, the thickness of which is 0.1 to 1 mm for example, the coefficient of linear expansion of which is 300°C or less and which is 2.5 to 4.5 [x 10^{-6}/°C] for example. The ink supply communicating port 21 may be also a slit 21A crossing the vicinity of the end on the side of the ink supply communicating port of each pressure generating chamber 12 or may be also plural slits 21B as shown in Figs. 3A and 3B. One surface of the sealing plate 20 covers one surface of the passage forming substrate 10 overall and also functions as a reinforcing plate for protecting the monocrystalline silicon substrate from an impulse and external force. The other surface of the sealing plate 20 constitutes one wall surface of the common ink chamber 31.

[0050] A common ink chamber forming substrate 30 forms the peripheral wall of the common ink chamber 31 and is made by punching a stainless steel plate with appropriate thickness according to the number of nozzle apertures and an ink droplet ejecting frequency. In this embodiment, the thickness of the common ink chamber forming substrate 30 is set to 0.2 mm.

[0051] An ink chamber side plate 40 is made of a stainless steel substrate and one surface constitutes one wall surface of the common ink chamber 31. A thin wall 41 is formed by forming a concave portion 40a in a part of the other surface by half-etching in the ink chamber side plate 40 and further, an ink inlet 42 via which ink is supplied from the outside is formed by punching. The thin wall 41 is provided to absorb pressure generated when an ink droplet ejects toward the reverse side of the nozzle aperture 11 and prevents unnecessary positive or negative pressure from being applied to another pressure generating chamber 12 via the common ink chamber 31. In this embodiment, the thickness of the ink chamber side plate 40 is set to 0.2 mm and the thickness of the thin wall 41 which is a part of the above ink chamber side plate is set to 0.02 mm in view of rigidity required when the ink inlet 42 and external ink supply means are connected and others, however, the thickness of the ink chamber side plate 40 may be also set to 0.02 mm from the beginning to omit the formation of the thin wall 41 by half-etching.

[0052] In the meantime, a lower electrode film 60 the thickness of which is set to approximately 0.5 μm for example, a piezoelectric film 70 the thickness of which is set to approximately 1 μm for example and an upper electrode film 80

the thickness of which is set to approximately 0.1 μm for example ar laminated on the elastic film 50 on the reverse side to the open face of the passage forming substrate 10 in a process described later and constitutes a piezoelectric element 300. The piezoelectric element 300 includes the lower electrode film 60, the piezoelectric film 70 and the upper electrode film 80. Generally, either electrode of the piezoelectric element 300 is made to function as a common electrode, and the other electrode and the piez electric film 70 are patterned every pressur generating chamber 12. A part constituted by patterned either electrode and the piezoelectric film 70 in which piezoelectric distortion is generated by applying voltage to both electrodes is called a piezoelectric active part 320. In this embodiment, the lower electrode film 60 functions as a common electrode of the piezoelectric element 300 and the upper electrode film 80 functions as an individual electrode for the piezoelectric element 300, however, even if they are reverse for the convenience of a driving circuit and wiring, they have no problem. In any case, a piezoelectric active part is formed every pressure generating chamber. The piezoelectric element 300 and a vibrating plate displaced by driving the piezoelectric element 300 are called a piezoelectric actuator in total. In the above example, the elastic film 50 and the lower electrode film 60 act as the vibrating plate, however, the lower electrode film may also function as the elastic film.

[0053] An insulating layer 90 for insulation from electricity is formed so that it covers at least the peripheral edge of the upper surface of the upper electrode film 80 and the side of the piezoelectric film 70. It is desirable that the insulating layer 90 is made of material which can be formed by a film forming method or can be reshaped by etching, for example silicon oxide, silicon nitride and organic material, desirably the insulating layer is formed by photosensitive polyimide low in rigidity and excellent in insulation from electricity.

[0054] Referring to Figs. 4, a process for forming the piezoelectric film 70 and others on the passage forming substrate 10 made of a monocrystalline silicon substrate is described below.

[0055] As shown in Fig. 4A, first, an elastic film 50 made of silicon dioxide is formed by the thermal oxidation of a wafer of a monocrystalline silicon substrate to be the passage forming substrate 10 in a diffusing furnace heated up to approximately 1100°C.

[0056] Next, as shown in Fig. 4B, a lower electrode film 60 is formed by sputtering. For the material of the lower electrode film 60, platinum Pt is suitable. The reason is that a piezoelectric film 70 described later formed by sputtering or sol-gel transformation is required to be crystallized by burning the formed piezoelectric film at the temperature of approximately 600 to 1000°C in atmospheric air or the atmosphere of oxygen. That is, it is desirable that the material of the lower electrode film 60 is required to secure conductivity in the above atmosphere of oxygen heated up to high temperature and particularly if lead zirconate titanate (PZT) is used for the piezoelectric film 70, it is desirable that conductivity is hardly changed by diffusing PbO and Pt being suitable for the above reason.

[0057] Next, as shown in Fig. 4C, the piezoelectric film 70 is formed. The piezoelectric film 70 may be also formed by sputtering, however, in this embodiment, so-called sol-gel transformation wherein so-called sol in which a metallic organic matter is dissolved and dispersed in a solvent gels by applying and drying the sol and further, the piezoelectric film 70 made of metallic oxide is obtained by burning the gel at high temperature is used. For the material of the piezoelectric film 70, PZT is suitable if it is used for an ink-jet printing head.

[0058] Next, as shown in Fig. 4D, an upper electrode film 80 is formed. The upper electrode film 80 has only to be made of conductive material and many metals such as Al, Au, Ni and Pt, conductive oxide and others can be used. In this embodiment, Pt is formed into a film by sputtering.

[0059] Next, as shown in Figs. 5, the lower electrode film 60, the piezoelectric film 70 and the upper electrode film 80 are patterned.

[0060] First, as shown in Fig. 5A, the lower electrode film 60, the piezoelectric film 70 and the upper electrode film 80 are etched together according to the pattern of the lower electrode film 60. Next, as shown in Fig. 5B, only the piezoelectric film 70 and the upper electrode film 80 are etched and a piezoelectric active part 320 is patterned. Next, as shown in Fig. 5C, a lower electrode film removed part 350 is formed by removing the lower electrode film 60 which is a part according to the arm of a vibrating plate on both sides of the piezoelectric active part 320 which is an area opposite to both sides in the direction of the width of each pressure generating chamber 12 shown by a broken line in Figs. 5. The quantity of displacement by applying voltage to the piezoelectric active part 320 is increased by providing the lower electrode film removed part 350 as described above.

[0061] The lower electrode film removed part 350 may be also thinned without removing the lower electrode film 60 completely. The lower electrode film removed part 350 is formed in a part according to the arm of the piezoelectric active part 320, however, the lower electrode film removed part is not limited to the above part, the lower electrode film removed part may be also formed up to the outside in the longitudinal direction of both ends of the piezoelectric active part 320 for example and may be also formed approximately overall the periphery of the pressure generating chamber 12. Needless to say, the lower electrode film removed part 350 is not necessarily required to be provided.

[0062] As described above, after the lower electrode film 60 and others are patterned, it is desirable that the insulating layer 90 for insulation from electricity is formed so that it covers at least the edge of the upper surface of the upper electrode film 80 and the side of the piezoelectric film 70 and the lower electrode film 60 as shown in Fig. 1.

[0063] A contact hole 90a exposing a part of the upper electrode film 80 to connect to a lead electrode 100 described

later is formed in a part of the part covering the upper surface of the part corresponding t one end of each piezoelectric active part 320 of the insulating layer 90. A lead electrode 100 one end of which is connected to each upper electrode film 80 via the contact hole 90a and the other end of which is extended to a connecting terminal is formed.

[0064] Fig. 6 shows such a process for forming th insulating layer and the lead electrode.

[0065] First, as shown in Fig. 6A, the insulating layer 90 is formed so that it covers the edge of the upper electrode film 80 and the side of the piezoelectric film 70 and th lower electrode film 60. The suitable material of the insulating layer 90 is described above, however, in this embodiment, negative photosensitive polyimide is used.

[0066] Next, as shown in Fig. 6B, the contact hole 90a is formed in a part corresponding to the vicinity of the end on the side of the ink supply port of each pressure generating chamber 12 by patterning the insulating layer 90. The contact hole 90a is provided to connect the lead electrode 100 described later and the upper electrode film 80. The contact hole 90a has only to be provided in a part corresponding to the piezoelectric active part 320 and for example, the contact hole may be also provided in the center and at the end on the side of a nozzle.

[0067] Next, the lead electrode 100 is formed by patterning an electric conductor after the electric conductor such as Cr-Au is formed overall.

[0068] The process for forming films is described above. After films are formed as described above, the monocrystalline silicon substrate is anisotropically etched by dipping the above alkaline solution as shown in Fig. 6C and a pressure generating chamber 12 and others are formed.

[0069] In such an ink-jet printing head, multiple chips are simultaneously formed on one wafer by the above series of forming films and anisotropic etching and after the process is finished, the wafer is divided into each passage forming substrate 10 in one chip size shown in Fig. 1. The sealing plate 20, the common ink chamber forming substrate 30 and the ink chamber side plate 40 are sequentially bonded to the divided passage forming substrate 10 and integrated to be an ink-jet printing head.

[0070] In the ink-jet printing head constituted as described above, after ink is taken in from the ink inlet 42 connected to the external ink supply means not shown and the inside from the common ink chamber 31 to the nozzle aperture 11 is filled with ink, pressure in the pressure generating chamber 12 is increased and an ink droplet ejects from the nozzle aperture 11 by applying voltage between the lower electrode film 60 and the upper electrode film 80 via the lead electrode 100 according to a recording signal from an external driving circuit not shown and flexuously deforming the elastic film 50, the lower electrode film 60 and the piezoelectric film 70.

[0071] Figs. 7 show positional relationship between the pressure generating chamber 12 and the piezoelectric active part 320 respectively formed as described above and the enlarged section of the vicinity of the end of the pressure generating chamber 12 when the piezoelectric active part 320 is driven.

[0072] As shown in Fig. 7A, the piezoelectric active part 320 composed of the piezoelectric film 70 and the upper electrode film 80 is provided in an area opposite to the pressure generating chamber 12 linearly. The elastic film 50 and the lower electrode film 60 are deformed so that they are convex upward in the vicinity of the peripheral wall of the pressure generating chamber 12 when they are viewed from the piezoelectric active part 320 as shown in Fig. 7B as the piezoelectric active part 320 is deformed by applying voltage and the elastic film 50 and the lower electrode film 60 are deformed in the most part of the pressure generating chamber 12 so that they are convex downward (concave). The end E of the piezoelectric active part 320 is located in a range in which the elastic film 50 and the lower electrode film 60 are concave when they are deformed as described above, that is, a range S in which the center of curvature is located on the side on which the piezoelectric film 70 is formed. This range S is a range in which the elastic film 50 is convex in a direction reverse to the side on which the piezoelectric active part 320 is provided and if the piezoelectric active part is provided under the elastic film, the end of the piezoelectric active part has only to exist in an area in which the elastic film is convex upward.

[0073] As no tensile stress is caused at the end of the piezoelectric active part 320 when the piezoelectric active part 320 is driven by constituting as described above and stress concentration in the vicinity of the peripheral wall of the pressure generating chamber 12 is reduced, these parts can be prevented from being peeled or a crack and others can be prevented from being caused in these parts. The condition of the above range S has only to be met at least when the piezoelectric active part is driven but the above effect is produced even if the elastic film is deformed in the reverse direction when the piezoelectric active part is not driven.

[0074] The patterned shape of the piezoelectric active part 320 is not particularly limited in this embodiment and for example, as shown in Fig. 8, the shape at the end of a piezoelectric active part 320A may be also approximately the same as the shape of the pressure generating chamber 12. In this case, the end of the piezoelectric active part 320A is a corner E1 protruded toward the end of the pressure generating chamber 12 and the corner E1 is formed so that it is located in the above range S. Further, for example, as shown in Fig. 9, the shape at the end of a piezoelectric active part 320B may be also approximately an arc and in this case, the piezoelectric active part 320B is formed so that the end E2 in the shape of an arc is located in the above range S.

[0075] To further effectively prevent a crack and others from being caused at the end of the piezoelectric active part 320 and in the vicinity of the end of the pressure generating chamber 12, a structure shown in Figs. 10 to 12 for example

may be also adopted in addition to the structure in this embodiment.

[0076] That is, as shown in Fig. 10, a piezoelectric inactive part 330 in which the upper electrode film 80 is removed and only the piezoelectric film 70 is formed, preferably also outside the end in the longitudinal direction of a piezoelectric active part 320C so as to reduce the vibration at the end in the longitudinal direction of the piezoelectric active part 320C. As the piezo lectric inactive part 330 is not driven by applying voltage to the piez electric active part 320C, vibration in the vicinity of the end of the piezoelectric active part 320C is reduced, and p eling, the generation of a crack and others in this part can be effectively prevented. In this case, the end of the piezoelectric active part 320C is according to a boundary E3 with the piezoelectric inactive part 330 and the piezoelectric active part 320C is formed so that the boundary E3 is located in the above range S.

[0077] The piezoelectric inactive part 330 may be also provided outside both ends, however, for example, it may be also provided only at the end near the contact hole 90a which functions as the contact part with the lead electrode 100.

[0078] Also, as shown in Fig. 11, a piezoelectric inactive part 330A may be also formed outside the end in the longitudinal direction of a piezoelectric active part 320D as in the structure shown in Fig. 10 so that the piezoelectric inactive part is extended up to over the peripheral wall across the end of the pressure generating chamber 12, that is, the piezoelectric inactive part 330A crosses a boundary between an area opposite to the pressure generating chamber 12 and an area opposite to the peripheral wall. Also in this case, as described above, the piezoelectric active part 320D is formed so that a boundary E4 with the piezoelectric inactive part 330A is located in the above range S.

[0079] Vibration by applying voltage is substantially prevented at the end of the piezoelectric active part 320D and in the vicinity of the peripheral wall of the pressure generating chamber 12 by constituting as described above, and the peeling of these parts, the generation of a crack in these parts and others can be effectively prevented.

[0080] Further, generally, a crack is readily caused in the piezoelectric film 70 and others in the vicinity of a boundary between the pressure generating chamber 12 and the peripheral wall by repeated displacement, however, as the piezoelectric film 70 in this part is the piezoelectric inactive part 330A, a crack is prevented from being caused in this part.

[0081] Furthermore, as shown in Fig. 12, a piezoelectric active part 320E is extended up to over the peripheral wall across the end of the pressure generating chamber 12 and a piezoelectric inactive part 330B the width of which is narrower though the piezoelectric inactive part is provided with the same lamination as the piezoelectric active part 320E and which is not substantially a driven part may be also provided in an area crossing the pressure generating chamber 12 and the peripheral wall. In this case, as a substantially driven part is the piezoelectric active part 320E, a boundary E5 between the piezoelectric active part 320E and the piezoelectric inactive part 330B is formed so that the boundary is located in the above range S.

[0082] Peeling, the generation of a crack and others at the end of the piezoelectric active part 320E and in the vicinity of the peripheral wall of the pressure generating chamber 12 when voltage is applied can be effectively prevented by constituting as described above. In the above structure, contact with the above lead electrode can be made outside the pressure generating chamber.

[0083] Fig. 13 is a plan showing the main part of an ink-jet printing head according to a second embodiment of the invention. The basic constitution in this embodiment is the same as that in the first embodiment, however, clearance Δy respectively between the shorter sides 320a and 320b at each end in the longitudinal direction of a piezoelectric active part 320 and the shorter sides 12a and 12b opposite to the above shorter sides of the peripheral wall of a pressure generating chamber 12 is set so that the clearance is in a predetermined range.

[0084] Such a predetermined range is determined based upon the following information: That is, when the value of the clearance Δy is larger than a fixed value, an elastic film 50 in an area opposite to each vicinity of the shorter sides 320a and 320b of the piezoelectric active part 320 is convex downward as in the above first embodiment, and the elastic film 50 and the piezoelectric active part 320 are prevented from being broken due to stress concentration. In the meantime, when the value of the clearance Δy exceeds a fixed value, the rigidity of the elastic film 50 is reduced, a crinkle is made in an area where the piezoelectric active part 320 does not exist in the elastic film 50 in the manufacturing process, ejecting an ink droplet becomes unstable and as the area of the piezoelectric active part 320 is reduced, performance when the piezoelectric active part is driven is deteriorated. The clearance Δy is varied depending upon the width X of the pressure generating chamber 12.

[0085] Table 1 shows the result of varying clearance Δy, applying a driving signal with the driving frequency of 14.4 kHz for an hour for example and examining relationship between the clearance Δy and whether the piezoelectric active part 320 is broken or not so as to acquire optimum clearance Δy. The following table 1 proves that if clearance Δy is 0.3 or more times as wide as the width X of the pressure generating chamber 12, the piezoelectric active part is not broken.

[0086] In the above range, it is verified that the elastic film 50 in an area opposite to the end of the piezoelectric active part 320 is convex downward. Therefore, as described in detail in the first embodiment, to locate the end of the piezoelectric active part 320 in an area in which the elastic film 50 is convex downward, it is verified that for example, the above clearance Δy has only to be 0.3 or more times as wide as the width X of the pressure generating chamber 12.

Table 1

Clearance	x0.1	x0.2	x0.3	x0.4	x0.5	x0.7	x0.9
Stress breaking modulus	10/10	4/10	0/10	0/10	0/10	0/10	0/10
Evaluation	X	X	O	O	O	O	O

[0087] Further, Table 2 shows the result of varying clearance Δy in a further large range and examining relationship between the clearance Δy and the rate of occurrence of a crinkle in the elastic film 50 after the passage forming substrate 10 is etched and the pressure generating chamber 12 is formed. The following table 2 shows that if clearance Δy is five or less times as wide as the width X of the pressure generating chamber 12, no crinkle is made.

Table 2

Clearance	X3	X4	X5	X6	X7	X8
Rate of occurrence of crinkle	0/10	0/10	0/10	3/10	8/10	10/10
Evaluation	O	O	O	X	X	X

[0088] The embodiments of the present invention as described above, are not to be understood as limiting the basic constitution of the ink-jet printing head according to the present invention.

[0089] For example, a common ink chamber forming plate 30 may be also made of glass ceramics in addition to the above sealing plate 20, further, a thin film 41 may be also made of glass ceramics separately and the material, the structure and others may be varied freely.

[0090] In the above embodiments, the nozzle aperture is formed on the end face of the passage forming substrate 10, however, a nozzle aperture protruded in a perpendicular direction to the end face may be also formed.

[0091] Fig. 14 is an exploded perspective view showing an embodiment constituted as described above and Fig. 15 shows the section of a passage. In this embodiment, a nozzle aperture 11 is made in a nozzle substrate 120 on the reverse side to a piezoelectric element and a nozzle communicating port 22 connecting the nozzle aperture 11 and a pressure generating chamber 12 pierces the sealing plate 20, the common ink chamber forming plate 30, a thin plate 41A and an ink chamber side plate 40A.

[0092] This embodiment is basically the same as the above embodiments except in that the thin plate 41A and the ink chamber side plate 40A are formed by different members and an opening 40b is formed in the ink chamber side plate 40, the same reference number is allocated to the same member and the description is omitted.

[0093] Also in this embodiment, as in the first and second embodiments, when a vibrating plate is deformed by applying voltage, stress concentration at the end of a piezoelectric active part and in the vicinity of the peripheral wall of the pressure generating chamber is reduced and a crack and others can be prevented from being generated respectively by locating the end of the piezoelectric active part in a range in which the center of curvature is located on the side of a piezoelectric film.

[0094] Needless to say, the present invention can be also similarly applied to an ink-jet printing head of a type that a common ink chamber is formed in the passage forming substrate.

[0095] In the above embodiments, a thin film type of ink-jet printing head which can be manufactured by applying a film forming and lithographic process is described as the example, however, needless to say, the present invention is not limited to the example and the present invention can be applied to ink-jet printing heads with various structures including a type that a pressure generating chamber is formed by laminating substrates, a type that a piezoelectric film is formed by sticking a green sheet, screen printing or others and a type that the piezoelectric film is formed by crystal growth.

[0096] Also in the above embodiments, basically a lead electrode is connected via the above contact hole 90a, however, the patterned shape of the lead electrode is not particularly limited.

[0097] Further, the example in which an insulating layer is provided between the piezoelectric element and the lead electrode is described above, however, the present invention is not limited to this example, an anisotropic conductive film may be also thermically welded to each upper electrode without providing the insulating layer, may be also connected to the lead electrode and may be also connected using various bonding technique such as wire bonding.

[0098] As described above, the present invention can be applied to ink-jet printing heads with various structures unless they are contrary to the object of the present invention.

[0099] The ink-jet printing heads according to thes embodiments respectively constitute a part of a printing head unit provided with an ink passage communicating with an ink cartridge and others and are respectively mounted in an ink-jet printing apparatus. Fig. 16 is a schematic drawing showing an example of the ink-jet printing apparatus.

[0100] As shown in Fig. 16, each cartridge 2A and 2B constituting ink supply means is respectively provided to each printing head unit 1A and 1B provided with an ink-jet printing head so that the cartridge can be detached and a carriage 3 mounting each printing head unit 1A and 1B is provided to a carriage shaft 5 attached to the body 4 of the apparatus so that the carriage 3 can be moved freely in the direction of the shaft. The printing head units 1A and 1B respectively jet a black ink composition and a color ink composition for example.

[0101] The carriage 3 mounting the printing head units 1A and 1B is moved along the carriage shaft 5 by transmitting the driving force of a driving motor 6 to the carriage 3 via plural gears not shown and a timing belt 7. In the meantime, a platen 8 is provided to the body 4 of the apparatus along the carriage shaft 5 and a recording sheet S which is a recording medium such as paper fed by a paper feed roller not shown or others is wound on the platen 8 and carried.

[0102] As described above, according to the present invention, when the vibrating plate is deformed by applying voltage, stress concentration at the end of the piezoelectric active part and in the vicinity of the peripheral wall of the pressure generating chamber can be reduced by forming so that an area including a part corresponding to the end of the piezoelectric active part is convex in the reverse direction to the piezoelectric element and a crack and others can be prevented from being caused. Driving voltage applied to the piezoelectric active part can be increased by further reducing stress.

Claims

1. An ink-jet printing head comprising a pressure generating chamber (12) communicating with a nozzle aperture (11), a vibrating plate constituting a part of said pressure generating chamber (12) and a piezoelectric element (300) corresponding to said pressure generating chamber (12), and the piezoelectric element (300) comprising a lower electrode (60), a piezoelectric layer (70), and an upper electrode (80), wherein said vibrating plate in an area opposite to the vicinity of at least one end in the longitudinal direction of a piezoelectric active part (320) of said piezoelectric element (300) is convex to said pressure generating chamber (12).

2. An ink-jet printing head according to claim 1, wherein said vibrating plate in an area opposite to the vicinity of the end of said piezoelectric active part (320) is convex to said pressure generating chamber (12) when said piezoelectric element (300) is driven, and said vibrating plate in an area opposite to the vicinity of the end of said piezoelectric active part (320) is convex to said piezoelectric element (300) when said piezoelectric element (300) is not driven.

3. An ink-jet printing head according to claim 2, wherein stress in a direction in which said vibrating plate is compressed is applied to the vicinity of the surface on the side of said piezoelectric layer (70) of said vibrating plate in an area opposite to the vicinity of the end of said piezoelectric active part (320) when said piezoelectric element (300) is driven.

4. An ink-jet printing head according to any one of claims 1 to 3, wherein clearance (Δy) between the end of said piezoelectric active part (320) and the peripheral wall of said pressure generating chamber (12) outside said piezoelectric active part (320) is set to a range 0.3 to 5 times as wide as the width of said pressure generating chamber (12).

5. An ink-jet printing head according to any of claims 1 to 4, wherein the end of said piezoelectric active part (320) is the end of said piezoelectric layer (70) provided to an area opposite to said pressure generating chamber (12), and said lower electrode (60) and said upper electrode (80) effectively exist at the end of said piezoelectric layer (70).

6. An ink-jet printing head according to claim 5, wherein the end of said piezoelectric active part (320) is the ends of said piezoelectric layer (70) and said upper electrode (80) patterned in an area opposite to said pressure generating chamber (12).

7. An ink-jet printing head according to any of claims 1 to 4 wherein a piezoelectric inactive part (330) in which a piezoelectric layer (70) not substantially driven exists is continuously provided outside at least one end in the longitudinal direction of said piezoelectric active part (320).

8. An ink-jet printing head according to any of claims 1 to 4, wherein a piezoelectric inactive part (330) in which the width of at least said piezoelectric layer (70) is narrower than the width of said piezoelectric active part (320) though

said piezoelectric inactive part (330) is provided with said piezoelectric layer (70), said lower electrode (60) and said upper electrode (80) and said vibrating plate is not substantially driven is continuously provided outside at least one end in the longitudinal direction of said piezoelectric active part (320).

9. An ink-jet printing head according to claim 7 or 8, wherein said piezoelectric inactive part (330) is provided in at least one direction in the longitudinal direction of said piezoelectric active part (320) and extended up t the peripheral wall of said pressure generating chamber (12).

10. An ink-jet printing head according to any of claims 1 to 9, wherein an insulating layer (90) is formed on the upper surface of said piezoelectric active part (320), and a contact part which is a connection of said upper electrode (80) and a lead electrode (100) is formed in a contact hole (90a) formed in said insulating layer (90).

11. An ink-jet printing head according to claim 10, wherein a contact part which is a connection of said upper electrode (80) and a lead electrode (100) is formed in an area which continues up to said piezoelectric inactive part (330) on the peripheral wall of said pressure generating chamber (12).

12. An ink-jet printing head according to any of claims 1 to 11, wherein said pressure generating chamber (12) is formed in a monocrystalline silicon substrate by anisotropic etching, and said vibrating plate and said piezoelectric element (300) are formed by film forming technique and lithography.

13. An ink-jet printing apparatus having an ink-jet printing head comprising a piezoelectric element (300) constituted substantially, via a vibrating plate constituting a part of a pressure generating chamber (12) communicating with a nozzle aperture (11), by a lower electrode (60), a piezoelectric layer (70), and an upper electrode (80), wherein said vibrating plate in an area opposite to the vicinity of at least one end in the longitudinal direction of a piezoelectric active part (320) which is an area in which said piezoelectric layer (70) substantially drives said vibrating plate is convex on the reverse side to said piezoelectric element (300).

14. An ink-jet printing head according to claim 13, wherein said vibrating plate in an area opposite to the vicinity of the end of said piezoelectric active part (320) is convex on the reverse side to said piezoelectric element (300) when said piezoelectric element (300) is driven, and said vibrating plate in an area opposite to the vicinity of the end of said piezoelectric active part (320) is convex in a reverse direction when said piezoelectric element (300) is not driven.

15. An ink-jet printing head according to claim 14, wherein stress in a direction in which said vibrating plate is compressed is applied to the vicinity of the surface on the side of said piezoelectric layer (70) of said vibrating plate in an area opposite to the vicinity of the end of said piezoelectric active part (320) when said piezoelectric element (300) is driven.

16. An ink-jet printing head according to claim 13, wherein clearance (Δy) between the end of said piezoelectric active part (320) and the peripheral wall of said pressure generating chamber (12) outside said piezoelectric active part (320) is set to a range 0.3 to 5 times as wide as the width of said pressure generating chamber (12).

17. An ink-jet printing head according to claim 13, wherein the end of said piezoelectric active part (320) is the end of said piezoelectric layer (70) provided to an area opposite to said pressure generating chamber (12), and said lower electrode (60) and said upper electrode (80) effectively exist at the end of said piezoelectric layer (70).

18. An ink-jet printing head according to claim 17, wherein the end of said piezoelectric active part (320) is the ends of said piezoelectric layer (70) and said upper electrode (80) patterned in an area opposite to said pressure generating chamber (12).

19. An ink-jet printing head according to claim 13, wherein a piezoelectric inactive part (330) in which a piezoelectric layer (70) not substantially driven exists is continuously provided outside at least one end in the longitudinal direction of said piezoelectric active part (320).

20. An ink-jet printing head according to claim 13, wherein a piezoelectric inactive part (330) in which the width of at least said piezoelectric layer (70) is narrower than the width of said piezoelectric active part (320) through said piezoelectric inactive part (330) is provided with said piezoelectric layer (70), said lower electrode (60) and said upper electrode (80) and said vibrating plate is not substantially driven is continuously provided outside at least one end

in the longitudinal direction of said piezoelectric active part (320).

21. An ink-jet printing head according to claim 19 or 20, wherein said piezoelectric inactive part (330) is provided in at least one direction in the longitudinal direction of said piezoelectric active part (320) and extended up to the peripheral wall of said pressure generating chamber (12).

22. An ink-jet printing head according to claim 13, further comprising an insulating layer (90) formed on the upper surface of said piezoelectric active part (320), and a contact part which is a connection of said upper electrode (80) and a lead electrode (100) is formed in a contact hole (90a) formed in said insulating layer (90).

23. An ink-jet printing head according to claim 22, wherein a contact part which is a connection of said upper electrode (80) and a lead electrode (100) is formed in an area which continues up to said piezoelectric inactive part (330) on the peripheral wall of said pressure generating chamber (12).

24. An ink-jet printing head according to claim 13, wherein said pressure generating chamber (12) is formed in a monocrystalline silicon substrate by anisotropic etching, and said vibrating plate and said piezoelectric element (300) are formed by film forming technique and lithography.

FIG. 1

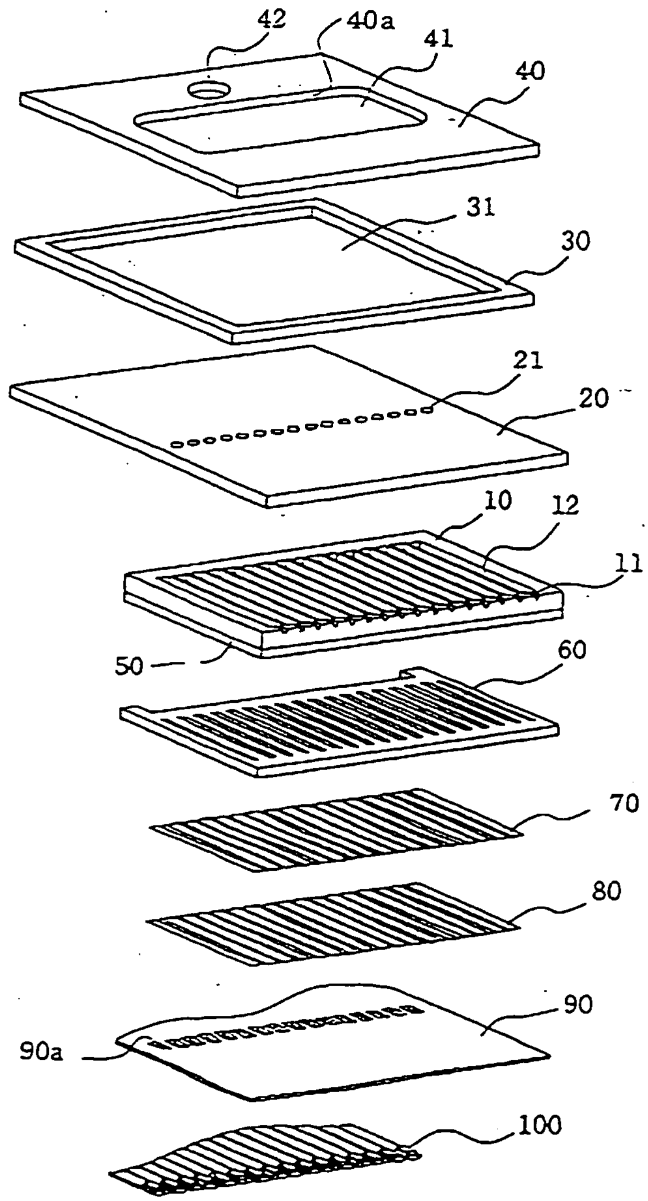


FIG.2A

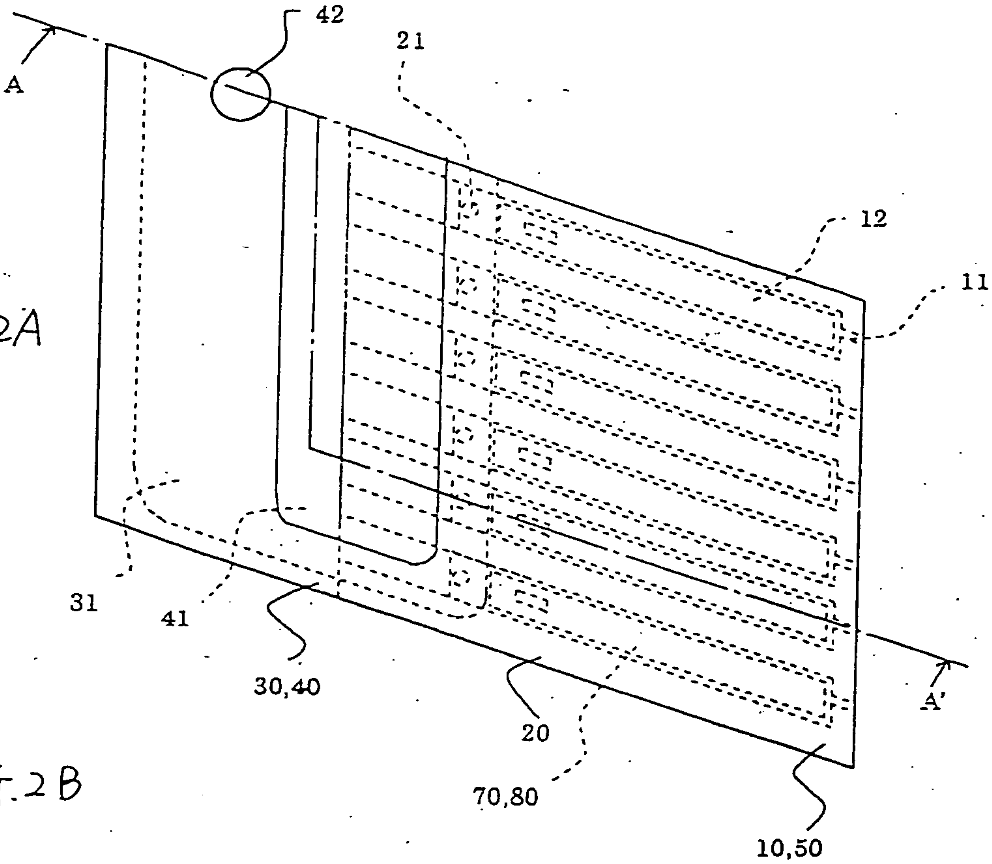

42
21
A
12
11
31
41
30,40
20
A'
70,80
10,50

FIG.2B

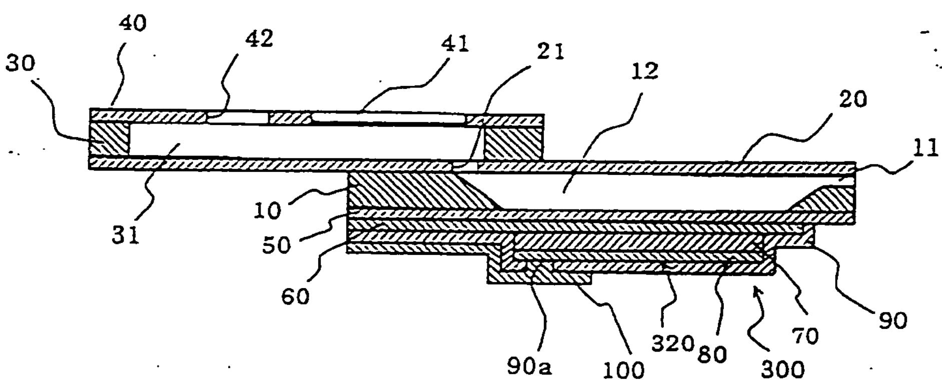

40
42
41
21
30
12
20
11
31
10
50
60
90
70
90a
100
320
80
300

FIG.3A

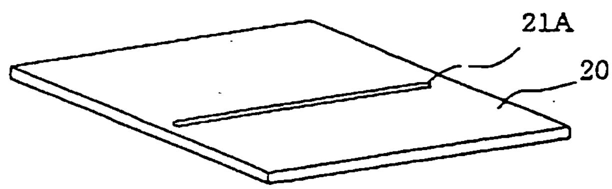


FIG.3B

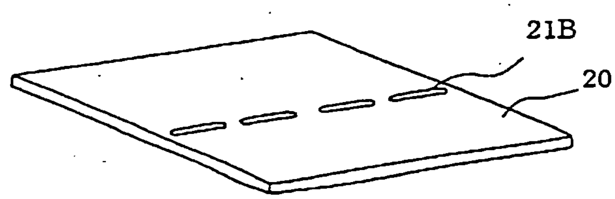


FIG.4A

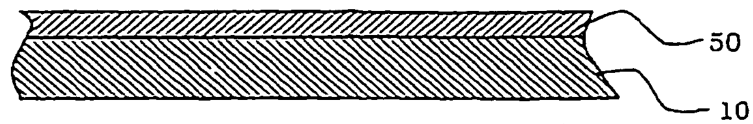


FIG.4B

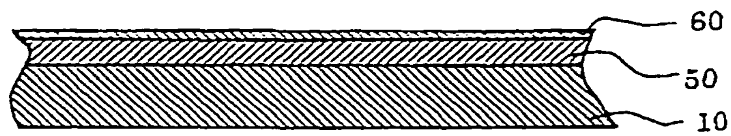


FIG.4C

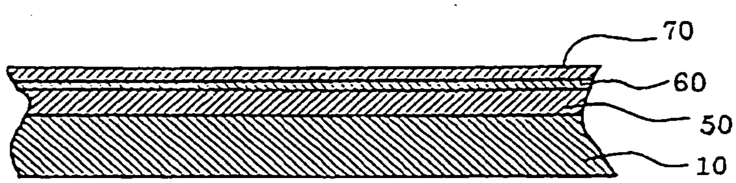


FIG.4D

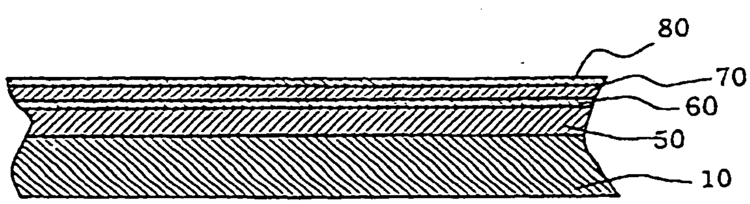


FIG. 5A

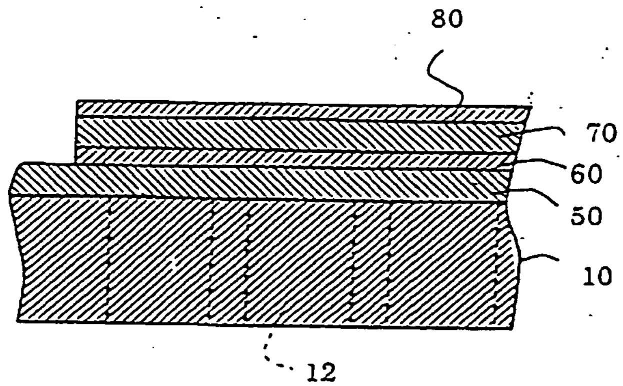


FIG. 5B

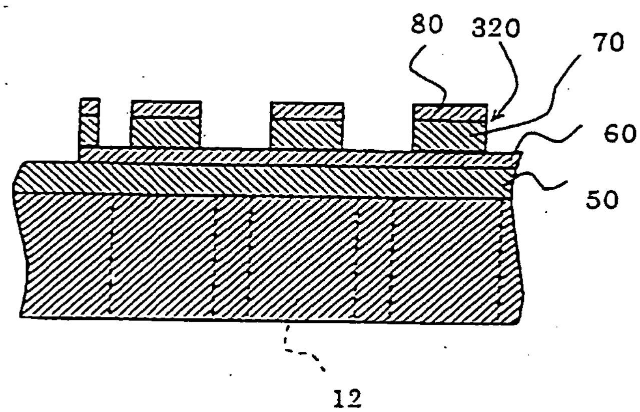


FIG. 5C

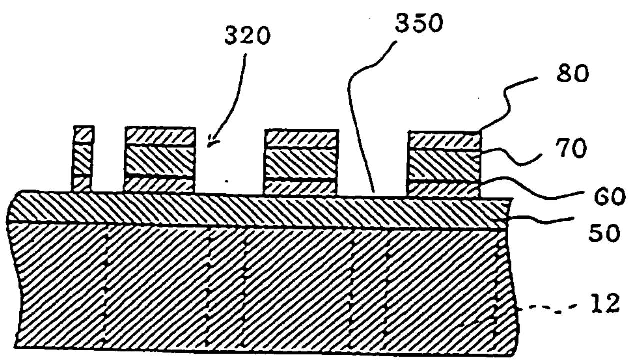


FIG.6A

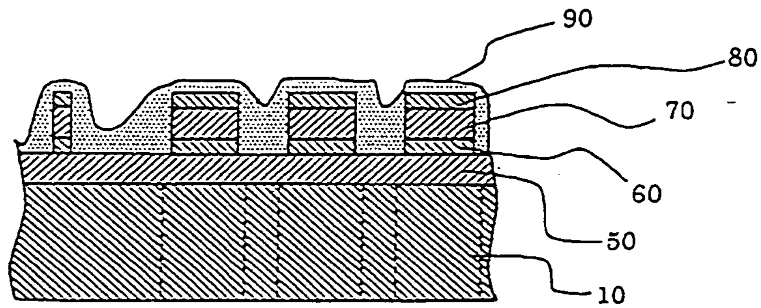


FIG.6B

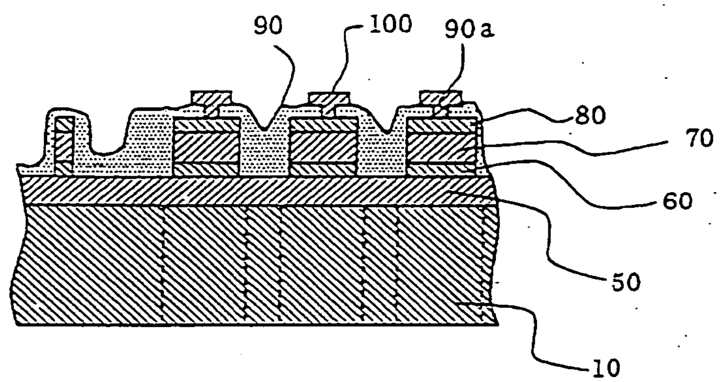


FIG.6C

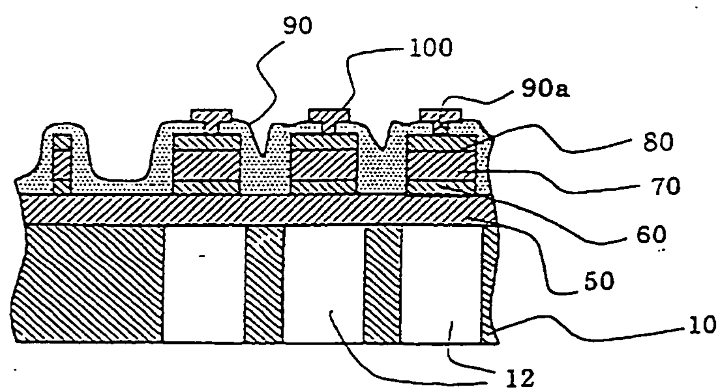


FIG.7A

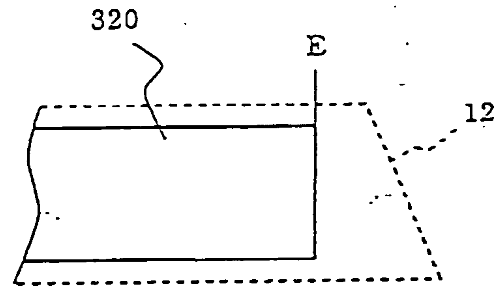


FIG.7B

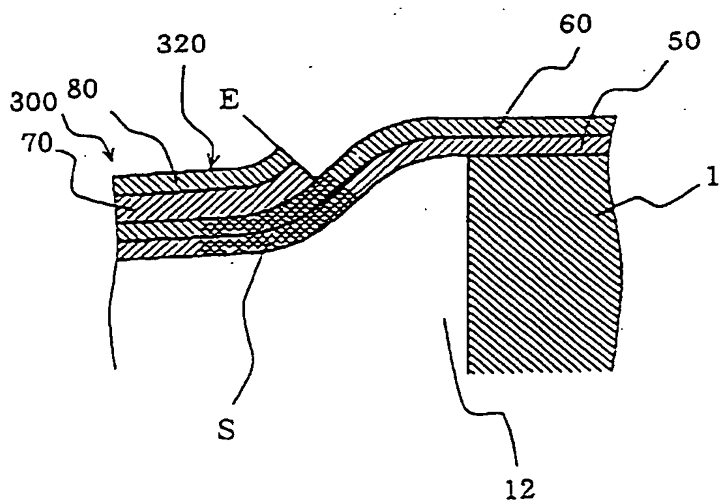


FIG. 8

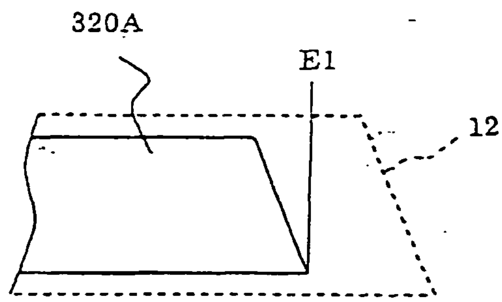


FIG. 9

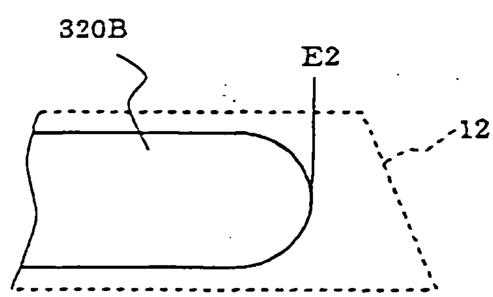


FIG. 10

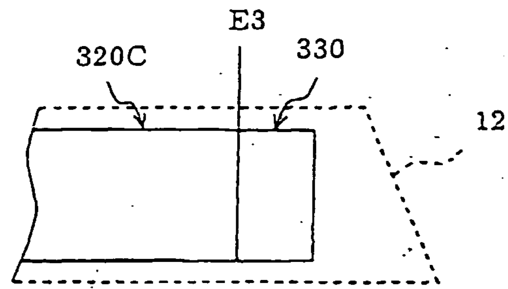


FIG. 11

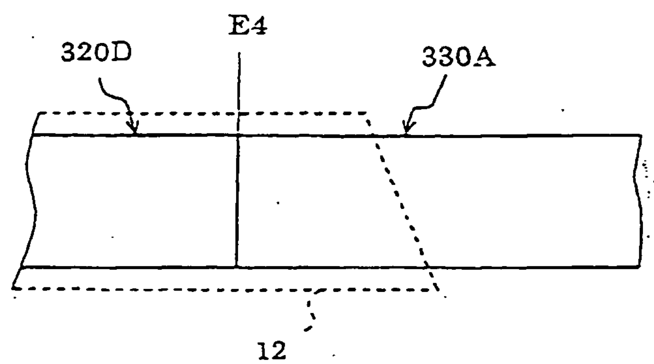


FIG. 12

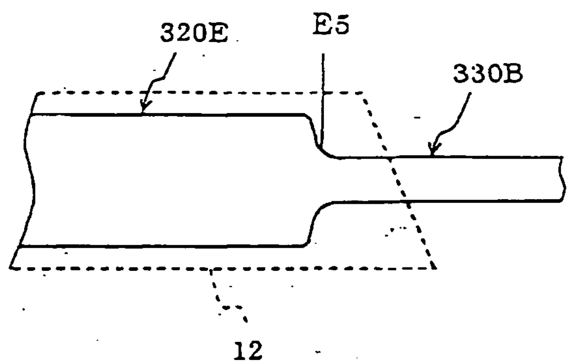


FIG. 13

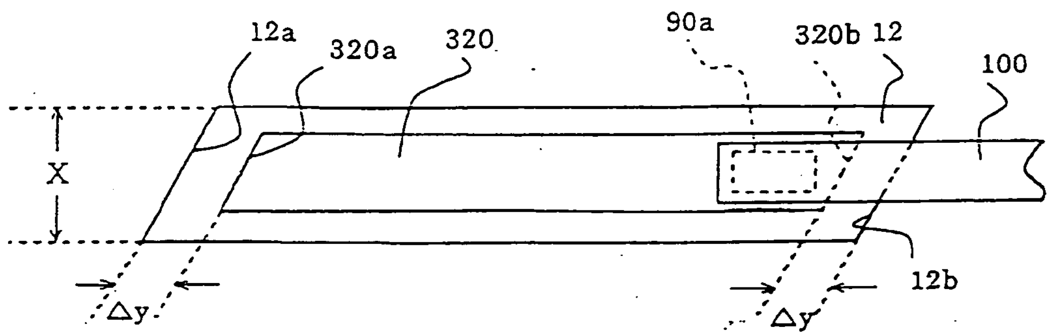


FIG. 14

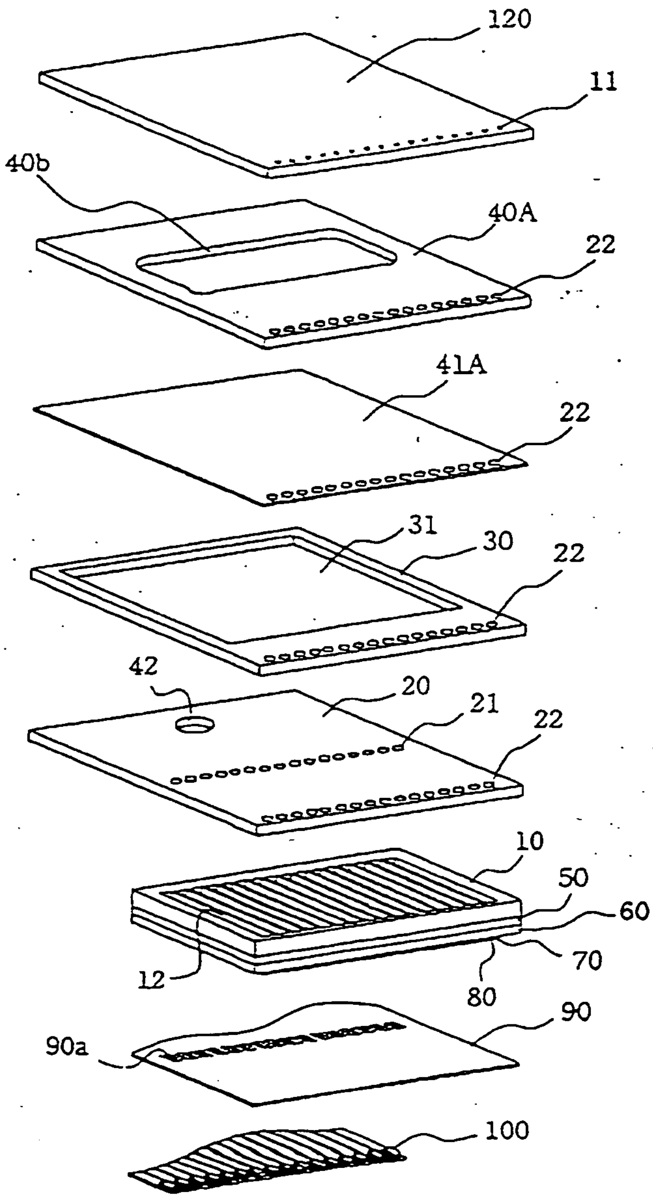

120
11
40b
40A
22
41A
22
31
30
22
42
20
21
22
10
50
60
12
70
80
90
90a
100

FIG. 15

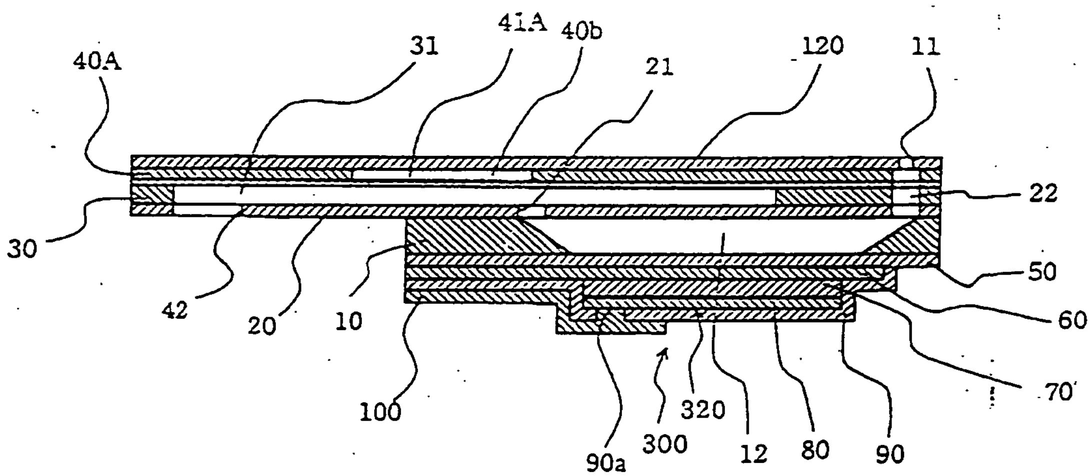

40A
31
41A
40b
21
120
11
22
30
50
42
20
10
60
100
70
320
90a
300
12
80
90

FIG.16